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TITLE- Saturn V Hold Limitations and Short Recycle Requirements During Terminal Countdown

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DATE- December 15, 1967

FILING CASE NO(S)- 320

AUTHOR(S)- C. H. Eley III

FILING SUBJECT(S)- Apollo-Saturn V Countdown
(ASSIGNED BY AUTHOR(S)-

ABSTRACT

This paper examines Apollo/Saturn V hold capability and short-recycle requirements during terminal countdown with respect to the vehicle's launch ability in meeting short launch windows.

A brief summary of the discussion is as follows:

a. As the terminal countdown progresses, the capability to hold is continually reduced while the launch delay incurred in the event of a short-recycle is continually increasing.

b. In conjunction with (a) above, a countdown to meet a short launch window is particularly vulnerable to short delays after T-22 minutes; the area of greatest vulnerability begins after T-8 minutes when SV hold capability is least and launch delay greatest for short-recycles.

c. If a short launch window is planned for a Saturn V launch, it would be most desirable to keep the window long enough (not less than, say, 30 minutes) for at least one contingency short-recycle unless otherwise necessitated by mission requirements. This could be accomplished either by the allowable length of a single window or the selection of two or more "panes."

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BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Saturn V Hold Limitations and Short Recycle Requirements During Terminal Countdown - Case 320

DATE: December 15, 1967

FROM: C. H. Eley III

TM 67-2032-4

TECHNICAL MEMORANDUM

I. INTRODUCTION

Terminal countdown for an Apollo/Saturn V space vehicle (SV) begins at T-45 minutes with the activation of spacecraft (SC) R.F. systems (Reference 1). During the terminal countdown, the hold capability and short recycle requirements are determined largely by stage thermal redline limits and J-2 engine sequences. These hold limitations are severe, and short holds occurring after T-22 minutes can adversely affect the progress of the countdown. This is particularly important in a countdown attempting to meet short launch windows or a "launch-on-time" requirement.

This paper examines the countdown operations during the period from T-45 minutes to T-0 with respect to SV hold capabilities and short recycle requirements. Much of the information presented was obtained from existing documentation and personnel at MSFC and KSC.

II. SPACE VEHICLE HOLD CAPABILITIES DURING TERMINAL COUNTDOWN

a. Hold Capability from T-45 Minutes to T-22 Minutes

SV hold capability during terminal countdown is not constrained until T-22 minutes. Prior to this time, there are no real limitations to holding at a particular T-time or to the required length of the hold (up to, say, four hours). There are, however, considerations in "desirable" hold points prior to T-22 minutes which will be discussed later.

b. Hold Capability from T-22 Minutes to T-15 Minutes

From T-22 minutes to start of the Terminal Countdown Sequencer (TCS) at T-187 seconds, the SV hold capability is constrained by stage thermal limits and J-2 engine sequences. As shown in Figure 1, the SV hold capability is limited to 10 minutes starting at T-22 minutes when S-II start tank chilldown is begun, until T-15 minutes.

There are five 4.2 cubic foot GH_2 turbine start tanks on the S-II stage and one on the S-IVB stage. These bottles are filled with cold (-250°F.) GH_2. Before filling, the bottles must be chilled since they are mass critical. This chilldown is started at T-22 minutes and continues until T-5 minutes when the start bottles are pressurized (completed by T-4 1/2 minutes). If a hold is required after T-22 minutes, the chilldown must continue uninterrupted to insure proper thermal conditioning. An additional ten minutes of chilldown is allowable before the start bottles become over-chilled. If the hold(s) exceeds ten minutes, the start bottles would be overchilled at T-0 if the countdown were continued. To prevent this, the countdown must be recycled to begin the chilldown sequence from the start (T-22 minutes).

c. Hold Capability from T-15 Minutes to T-8 Minutes

The SV hold capability during this period is determined by a combination of two conditions:

1. Thermal environment limitations in the S-II/ S-IVB interstage area.

2. The amount of "cumulative" hold time experienced after T-22 minutes.

In conjunction with (1) above, the launch vehicle is limited to a hold capability of five minutes when S-IVB J-2 engine thrust chamber chilldown is initiated at T-15 minutes (Figure 1). Gaseous helium is used to both purge the engine area of oxygen or ambient air and to prechill the engine for start requirements. The cold helium (-260°F.) is introduced at a rate of 10-20 lb./min. through the thrust chamber prechill port located downstream of the main oxygen valve. As a result, the chilldown process produces a rapid cooling of the environment in the S-II stage forward skirt area containing electronic components. If one or more holds occur after S-IVB J-2 chilldown has started, a "cumulative" hold time of five minutes can be tolerated before the lower temperature limits of the electronic components (-65°F.) will be exceeded by the time T-0 is reached.

To avoid any misconceptions, it should be noted that thrust chamber chilldown is <u>not</u> stopped during a hold. This is because hot GN_2 (+200°F) is also being introduced into the interstage area at rates of 33 and 300 lb./min. to help control the environment. If chilldown were stopped, the J-2 engine would rapidly warm-up and the chilldown would

have to be started all over again (from T-15 minutes). If both gas supplies were stopped, the thermal conditions still decay such that chilldown would have to be started all over again anyway. In other words, the countdown would have to be recycled.

In conjunction with (2) above, it must be remembered that the hold capability after T-15 minutes is also "cumulative" with respect to SV hold capability between T-22 and T-15 minutes. That is, the total time of all holds after T-22 minutes cannot exceed 10 minutes. Thus, if the SV countdown were held just prior to T-15 minutes for, say, 7 minutes, then a "cumulative" hold capability of only 3 minutes would remain after T-15 minutes for reasons other than J-2 thrust chamber chilldown constraints (Section II,b).

d. Hold Capability from T-8 Minutes to T-187 Seconds

As also shown in Figure 1, at T-8 minutes the S-II stage J-2 engine thrust chamber chilldown sequence is initiated, further reducing the SV hold capability to two minutes. Since there are five J-2 engines in the S-II as opposed to only one in the S-IVB, the increased flow of cold helium (~75 lb./min.) for chilldown produces a more rapid temperature drop in the S-IC forward skirt area surrounding the S-II engines than in the S-II forward skirt area around the S-IVB engine. The change in S-IC/S-II interstage temperature during the last eight minutes of countdown can be seen in Figure 2.

The following table lists the gases introduced into the S-IC/S-II interstage area during this period together with their flow rates and temperatures.

Gas	Flow Rate	Temp.	Area Required
GN_2	28.5 lbs./min.	125°F.	S-IC Elec. Canisters
GN_2	36.5 lbs./min.	105°F.	S-IC Elec. Canisters
GN_2	500 lbs./min	215°	Interstage Dump
GN_2	30 lbs./min.	120°F	S-IC Elec. Canisters
GHe	75 lbs./min.	~-260°F	J-2 T.C. Chilldown

A hold exceeding two minutes after starting S-II thrust chamber chilldown will allow the temperature of the electronics in the interstage to drop below redline limits by the time T-0 is reached. This hold capability is also "cumulative," and for the same reasons as previously described in (c) above.

e. Hold Capability from T-187 Seconds to T-0

At T-187 seconds, the Terminal Countdown Sequencer (TCS) is initiated which controls final countdown sequences automatically through the ESE interlock system. If a malfunction is detected after T-187 seconds, the ESE will send a cutoff signal to the TCS--stopping the countdown. (Cutoff can also be manually initiated if required.) The TCS cannot be reset, re-initiated and the automatic sequence re-run before the temperature in the S-IC forward skirt area drops below redline limits. Hence, once the TCS has started, virtually no hold capability exists and the countdown must be recycled to T-22 minutes if the countdown stops.

A hold for any reason after T-16.7 seconds (S-IC forward service arm retract) will adversely impact launch operations by causing a scrub. (The reasons for this are discussed in Section III.)

III. SPACE VEHICLE SHORT RECYCLE REQUIREMENTS

a. Short-Recycle Requirements Prior to T-22 Minutes

Prior to T-22 minutes in the countdown, the SV can be recycled to any T-time in the terminal countdown without penalty. That is, the time required to recycle back to a previous T-time is negligible.

b. Short-Recycle Requirements After T-22 Minutes

Figure 3 shows the time required to perform a short-recycle and launch from any point in the terminal countdown. As previously mentioned, the SV must be recycled if the hold limitations after T-22 minutes are exceeded. If a short-recycle is required, the various chilldown operations are stopped and the countdown clock is returned to T-22 minutes. The time required to do this is negligible. After recycling, however, the countdown must be held at T-22 minutes for a short period of time. This is needed to allow the temperature in the interstage areas to stabilize, and also to complete preparations for starting the countdown again. For a recycle prior to T-8 minutes, the SV must be held at T-22 minutes for at least six minutes. If the recycle is performed after T-8 minutes, the SV must be held at T-22 minutes for at least eight minutes. The additional two minutes of hold required for a turnaround after T-8 minutes are due to S-IC/S-II interstage thermal requirements.

Short recycle/countdown requirements do not change after initiation of the TCS at T-187 seconds, although the SV has no hold capability after that time. If a cutoff signal stops the countdown (prior to T-16.7 seconds), the

requirements remain as previously outlined--namely, the countdown is recycled back to T-22 minutes and a warm-up period of eight minutes is necessary before resuming the count.

c. Recycle Capability After T-16.7 Seconds

At T-16.7 seconds, the TCS issues a signal which initiates retraction of Swing Arm #2 (S-IC Forward Service Arm). After the arm has been retracted, it can only be reconnected manually. This service arm contains electrical and pneumatic connections--but most important, it is the supply source of hot GN_2 for the S-IC/S-II interstage area. The thermal environment cannot be controlled even if the countdown is recycled back to T-22 minutes. Thermal redlines, therefore, would soon be exceeded in the event of a hold. Since Swing Arm #2 cannot be reconnected by remote means, the LV cryogenics must be detanked to permit safe access before the arm can be manually reconnected. In other words, after T-16.7 seconds the SV is committed to either launch or scrub.

IV. SHORT RECYCLE LIMITATIONS

As previously indicated, S-II start bottle chilldown is begun at T-22 minutes in the countdown and S-IVB start bottle chilldown is begun at T-18 minutes. Both of these chilldowns continue until about T-4 1/2 minutes when the bottles are pressurized prior to start of the TCS.

A total of six GH_2 turbine start bottles (five on the S-II stage and one on the S-IVB stage) are chilled and pressurized from GSE coolers which, in turn, are fed from a 6000 psi storage battery located at the pad. Based on AS-501 data from LC-39 operations, it is expected that Douglas will use about 97 pounds of GH_2 during the S-IVB sequence. North American equipment at LC-39 used a GH_2 flow rate of 22 lbs./min., so a 17 minute chilldown and charge sequence in the S-II stage will use 374 pounds of GH_2. A nominal Saturn V countdown, then, requires about 471 pounds of GH_2. In order to repeat the J-2 chilldown and charge cycle described above (in the event of a short-recycle), the same amount of GH_2 is required each time.

The storage battery supplying gaseous hydrogen holds 352,000 Standard Cubic Feet (SCF) of GH_2 under pressure between 6000 and 1600 psig. At 471 pounds or 90,413 SCF of GH_2 required per chilldown and charge sequence, the storage system will support a maximum of three complete cycles before

having to be recharged. This would include the original terminal countdown plus two short-recycles from a point after T-4 1/2 minutes. The storage system could possibly support more than three short-recycles. However, this would greatly depend on what points in the countdown (prior to T-4 1/2 minutes) the recycles occurred and the amount of hold time used.

Recharging the pad GH_2 storage battery presently cannot be performed during the countdown. Normally there are two recharging units available, but these are mobile units and no provisions exist for remote operation. The hydrogen rechargers are each rated at 6000 psi, 500 Standard Cubic Feet per Minute (SCFM). During recharging operations, one unit is used while the second is a standby. About 10 hours are required for one recharger to return the GH_2 storage facility to full capacity. Without the capability for remote operations, hydrogen recharging cannot be started until the pad area is open for access (i.e. not until after launch vehicle cryogenics have been detanked). It can be seen, therefore, that a constraint will exist if the capability is required to perform more than three complete J-2 chilldown and charge sequences.

V. LAUNCH ABILITY AND SHORT LAUNCH WINDOWS

A set goal of any countdown is to launch at the beginning of the launch window. The length of a launch window only serves as a hedge against prior contingencies which can cause delays. Built-in holds can also be utilized to absorb delays--up to a point. In the case of the Apollo/Saturn V that point is, at the latest, T-22 minutes. After this, any delays due to holds and/or short-recycles must be absorbed by time available in the launch window or the countdown will be scrubbed.

In the preceding sections, Saturn V hold limitations and short-recycle requirements have been presented and shown in Figures 1 and 3. Figure 4 is a combination of Figures 1 and 3, showing SV launch ability by hold or short-recycle. The NOT AVAILABLE area indicated in Figure 4 is that portion of a launch window which cannot be reached by any combinations of holds or recycles once the countdown has progressed to a T-time later than T-18 minutes. Stated another way, this represents the minimum launch delay incurred for a single short-recycle (without first holding). The "Hold Line" represents the launch delay expected if the countdown is recycled following the maximum possible hold at any T-time. The effect of all this serves to point up the following:

a. As the terminal countdown progresses, the capability to hold is continually reduced while the launch delay incurred in the event of a short-recycle is continually increasing.

b. In conjunction with (a) above, a countdown to meet a short launch window is particularly vulnerable to short delays after T-22 minutes; the area of greatest vulnerability begins after T-8 minutes when SV hold capability is least and launch delay greatest for short-recycles.

c. If a short launch window is planned for a Saturn V launch, it would be most desirable to keep the window long enough (not less than 30 minutes) for at least one contingency short-recycle unless otherwise necessitated by mission requirements. This could be accomplished either by the allowable length of a single window or the selection of two or more "panes."

In planning for the first lunar mission, there are several advantages to be gained by using shorter launch windows--notably, reduced support requirements and a relative gain in final payload capability. In this regard, a current Apollo program objective is to increase the capability of the Apollo/Saturn V to launch "on-time." AS-501 recently demonstrated an "on time" launch. Nevertheless, if a shorter launch window is desired for the lunar mission, it would appear wisest not to restrict the launch window length any more than is absolutely necessary to satisfy mission requirements.

2032-CHE-gmp

C. H. Eley III

Attachments
Figures 1-4

REFERENCES

1. Apollo/Saturn V S/V Countdown - AS-501, Revision 1, dated November 1, 1967.

2. Requirements Study - KSC - Gas and Propellants, dated February 2, 1967, by Bendix Launch Support Division.

3. Saturn Interface Control Document, S-IC to S-II Stage Functional Requirements - 13M07000A.

4. Apollo/Saturn V Launch Mission Rules Revision A, Apollo 7, (AS-501) dated October 31, 1967.

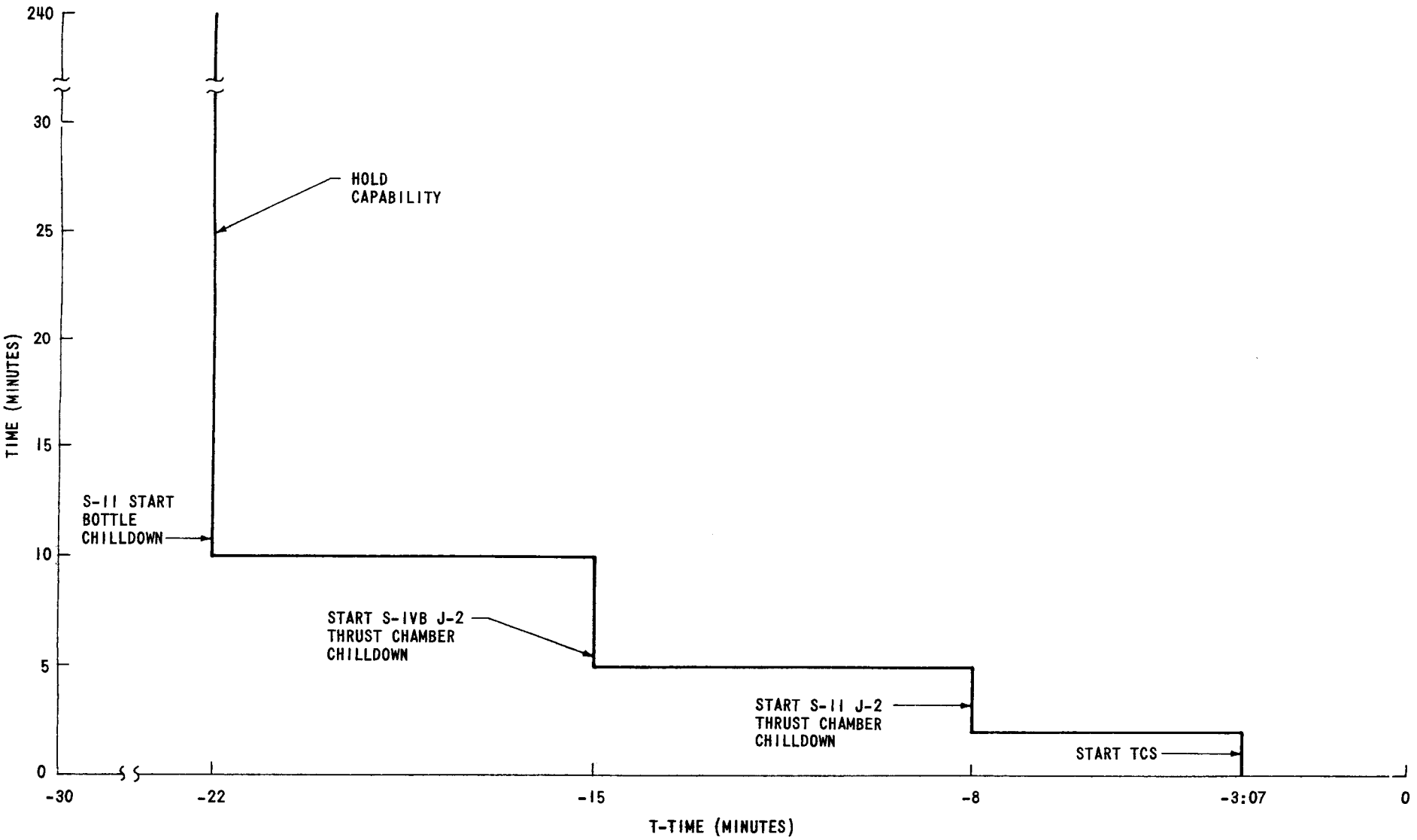

FIGURE I SATURN V HOLD CAPABILITY VRS. T-TIME OF HOLD

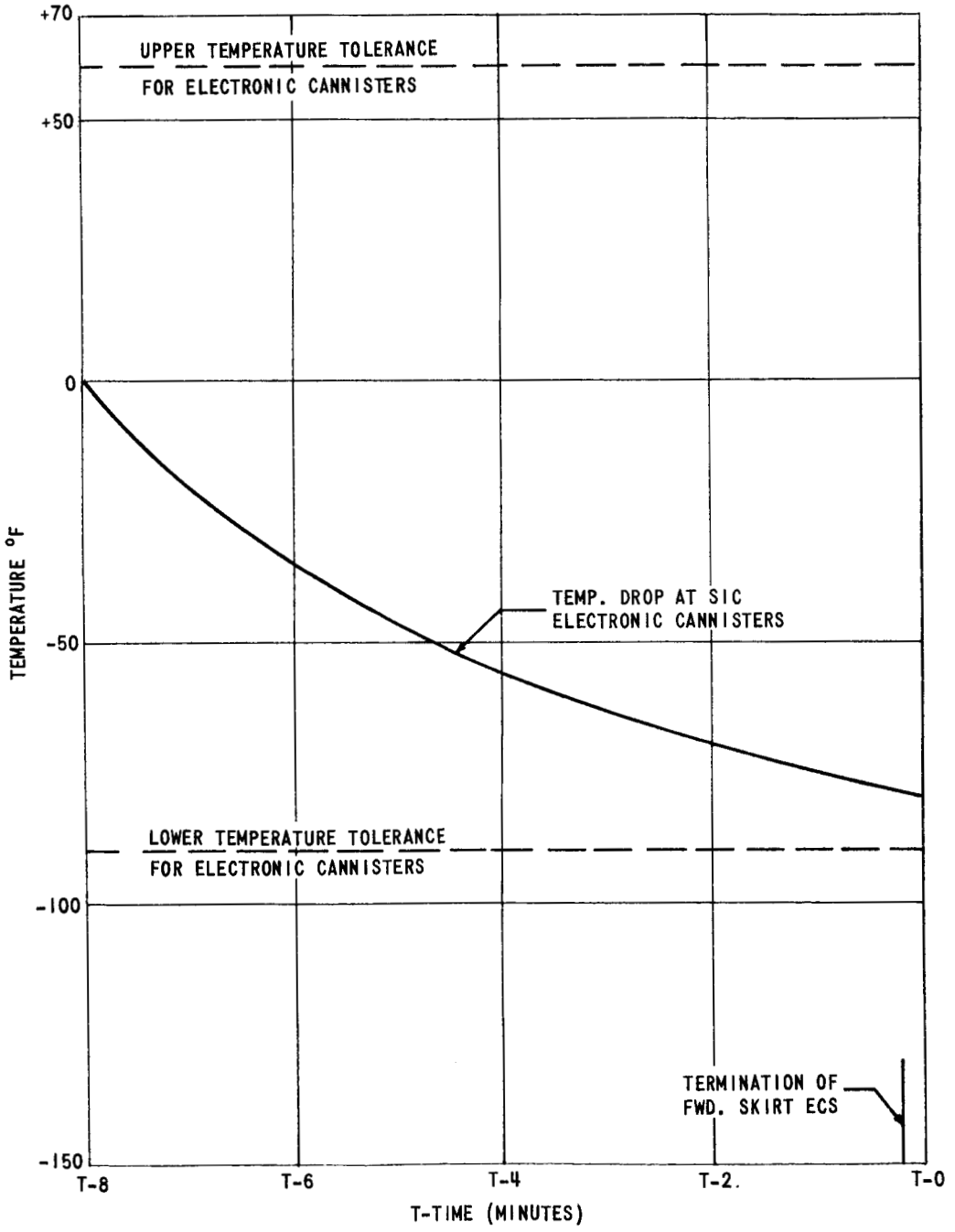

FIGURE 2 - SIC FWD. SKIRT THERMAL ENVIRONMENT
DURING S-II STAGE J-2 CHILLDOWN

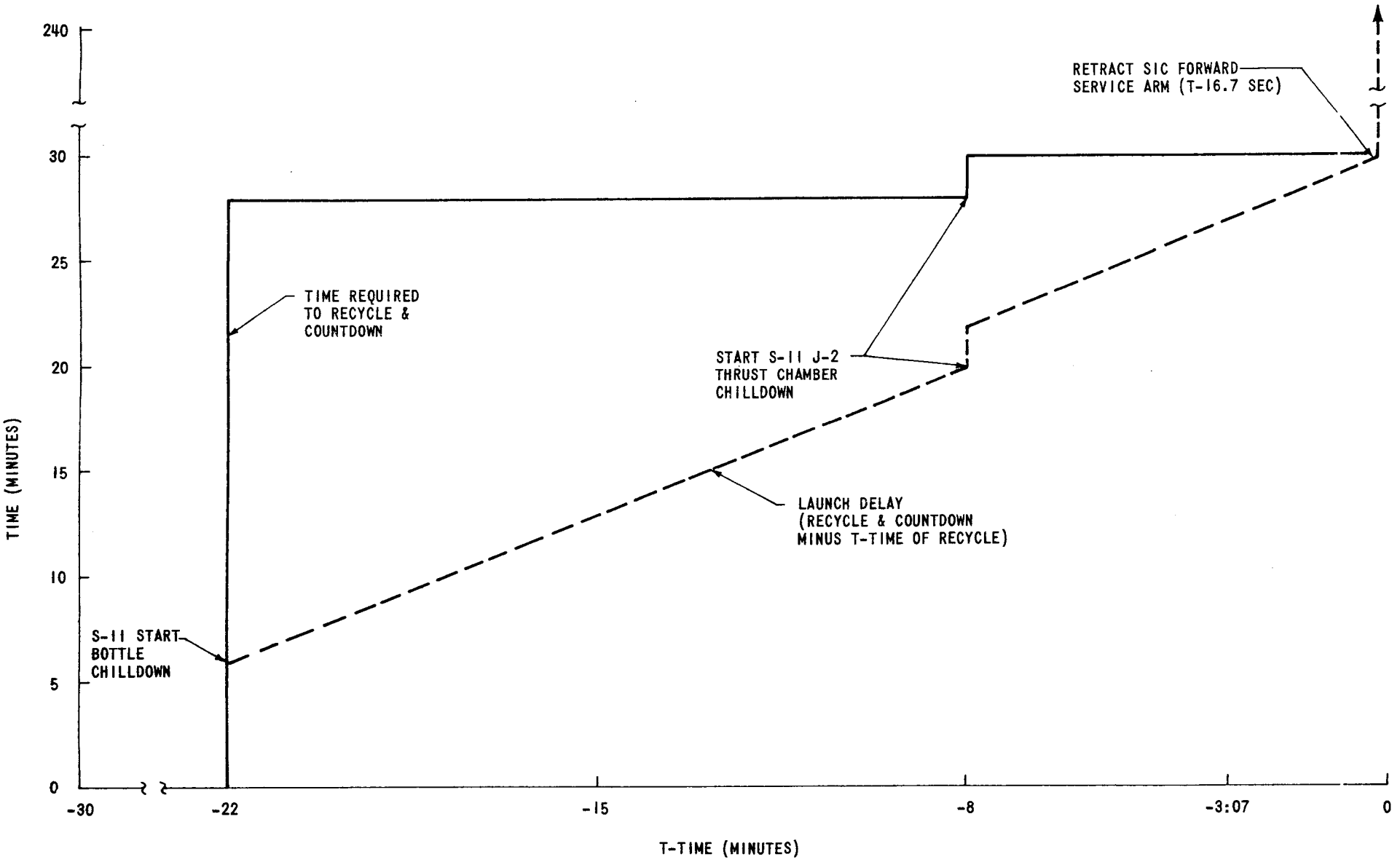

FIGURE 3 SATURN V SHORT RECYCLE/COUNTDOWN VRS. T-TIME OF RECYCLE

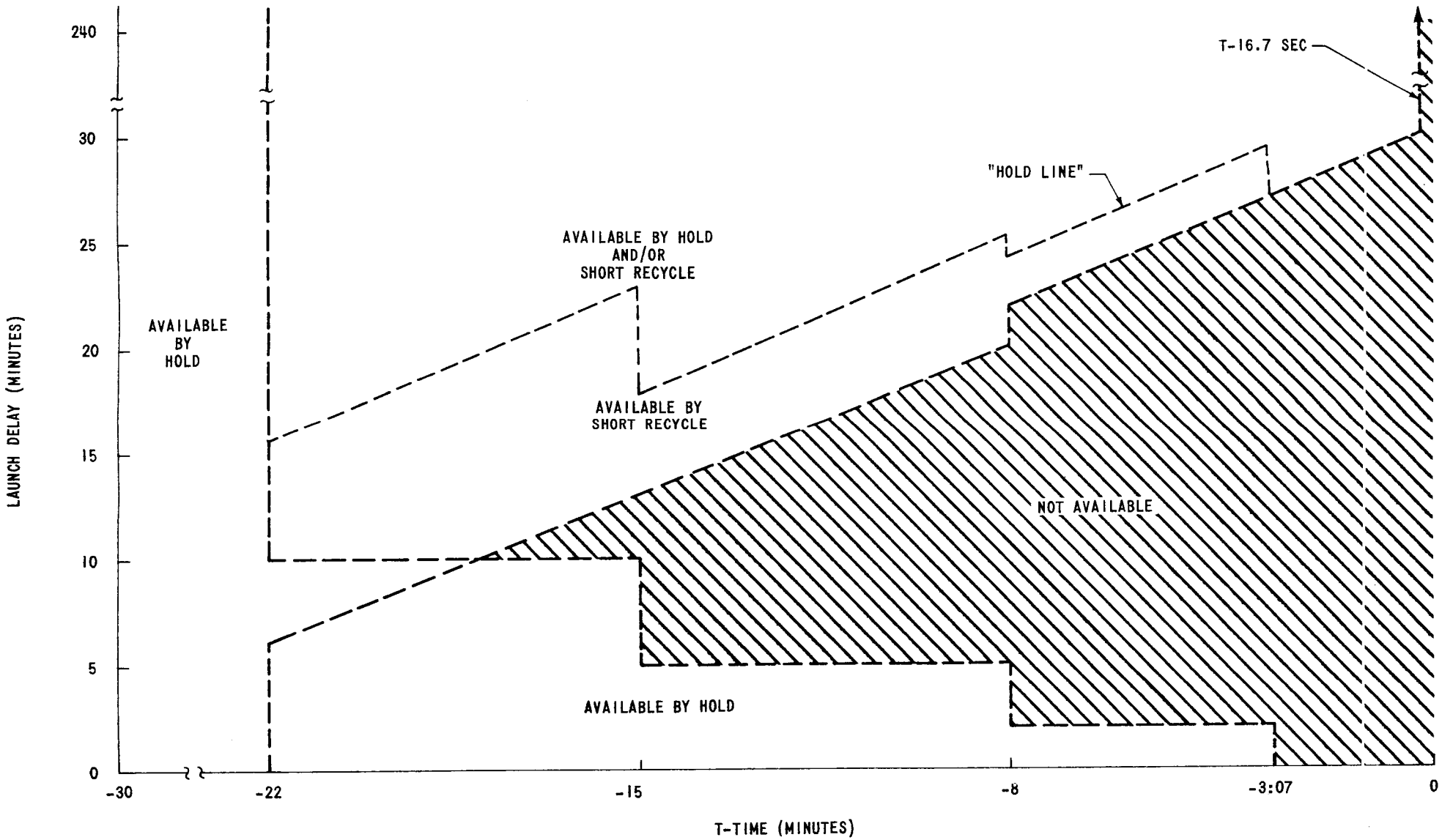

FIGURE 4 LAUNCH ABILITY BY HOLD OR SHORT RECYCLE